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THE FEASIBILITY OF CONCENTRATING/SEPARATING DILUTE NITROCELLULOSE ACID WASTEWATERS BY REVERSE OSMOSIS

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Fort Belvoir, Virginia

November 1974

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In cooperation with Picatinny Arsenal's Pollution Abatement Program and in response to their Procurement/Work Directive PRON: GG-325205-01-GG-EF, a feasibility study focused on the application of membrane technology for the concentration and/or separation of dilute acid wastewaters was conducted by the Sanitary Sciences Division, USAMERDC. Preliminary laboratory investigations using commercially available cellulose-acetate reverse osmosis (RO) membranes were conducted at Radford Army Ammunition Plant (RAAP) by plant personnel. The objective of this study was to

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concentrate the dilute acids as a unit process toward abating the nitrate pollution problem or as an intermediate step in the recovery of the nitric and sulphuric acids. Results of these preliminary investigations indicated that RO was a potential candidate for larger scale application and, therefore, more detailed work was warranted. Of special interest was the development of an acid-resistant membrane to counter the susceptibility of cellulose-acetate to hydrolysis when continuously exposed in an acidic environment.

Based on the data obtained in the laboratory phase of this study and subject to the data generated in the pilot plant phase, the following conclusions appear valid:

a. The application of cellulose-acetate and modified sulfonated polyphenylene oxide RO membranes as a unit process in the treatment of dilute acid wastewaters generated at RAAP is technically feasible.

b. The concentration of nitric and sulphuric acid at acceptable rates for engineering scale-up using RO is feasible and attainable.

c. The permeation or flux rates attainable in the treatment of RAAP acid wastewaters are acceptable for engineering scale-up.

d. Hydrolysis of the cellulose-acetate membrane did not significantly impair the performance characteristics of the RO modules.

e. Acidic corrosion of the metallic components of the RO system can introduce operational problems that will significantly interfere with the rejection and flux rates of the RO membranes.

f. Continuation of the program into a Phase II RO pilot plant operation located at RAAP for on-site evaluation and performance documentation and/or verification is justified.

PREFACE

The investigation covered in this report was conducted under the authority of Picatinny Arsenal Pollution Abatement Program Procurement/Work Directive PRON: GG-325205-01-GG-EF. The period covered is from August 1972 to June 1974.

The work was accomplished by LTC Vincent J. Ciccone under the supervision of Richard P. Schmitt, Chief, Sanitary Sciences Division (SSD) and Kennedy K. Harris, Chief, Military Technology Department. Data acquisition was accomplished by James M. McCann and Robert G. Ross of SSD. Data analysis was carried out by Genevieve Meyer; David B. Scott, Jr.; and Arthur L. Nickless of the Analysis and Programs Division, USAMERDC.

CONTENTS

Section	Title	Page
	PREFACE	iii
	ILLUSTRATIONS	v
	TABLES	vi
I	INTRODUCTION	
	1. Subject	1
	2. Background	1
II	INVESTIGATION	
	3. Technical Approach	1
	4. Results	3
III	DISCUSSION	
	5. Discussion	17
IV	CONCLUSIONS	
	6. Conclusions	19
	APPENDIXES	
	A. Rejection Model Mathematics	20
	B. Fortran Program – Rejection Model	22
	C. Computer Analysis – Observed Data	40

ILLUSTRATIONS

Figure	Title	Page
1	Simplified Schematic Flow Diagram for Laboratory Setup	2
2	Concentration of Nitrates in Brine Tank vs Time	7
3	Concentration of Sulfates in Brine Tank vs Time	8
4	Volume in Product Tank vs Time	9
5	Typical Acid Wastewater from RAAP	11
6	Typical Section of Cellulose Acetate RO Membrane After Exposure to Acid Wastewater	13
7	Typical 2-Inch-Diameter SPPO Module – in Bench Scale Setup	15
8	Flux vs Time, Cellulose Acetate RO Membrane	18

TABLES

Table	Title	Page
1	Acid Composition of Wastewater from Nitrocellulose Area – Boiling Tub Pit	2
2	Impurity No. 1 (Nitrates) Brine Tank Concentration vs Time	4
3	Impurity No. 2 (Sulfates) Brine Tank Concentration vs Time	4
4	Impurity No. 1 (Nitrates) Product Tank Concentration vs Time	5
5	Impurity No. 2 (Sulfates) Product Tank Concentration vs Time	5
6	Volume in Product Tank vs Time	6
7	Calculated Values for Engineering Design Parameters	6
8	Calculated Module Product Ion Rate	10
9	Modified Sulfonated Polyphenylene Oxide Membrane Evaluation	10

THE FEASIBILITY OF CONCENTRATING/SEPARATING DILUTE NITROCELLULOSE ACID WASTEWATERS BY REVERSE OSMOSIS

I. INTRODUCTION

1. **Subject.** This report covers a Picatinny Arsenal-financed study of the feasibility of membrane technology for the concentration and/or separation of dilute acid wastewaters.

2. **Background.** Acid wastewaters are generated in the manufacture of explosives and propellants. The primary pollutants are nitrates in the form of nitric acid and sulfates in the form of sulfuric acid. Nitric acid is generally the nitrating agent used in the production of such commodities as trinitrotoluene (TNT), nitroglycerin (NG), nitrocellulose (NC), and nitroguanidine. Sulfuric acid smooths the nitration reaction and absorbs the water released by esterification. Pollution results from the numerous rinsings following the nitration step and also from spills, leaks, and washdown operations from the manufacturing processes involved in the production of nitric acid and inorganic nitrates.

II. INVESTIGATION

3. **Technical Approach.** The bench scale phase of this project using commercially available cellulose-acetate RO membranes was designed to demonstrate the feasibility of concentrating/separating the spent acid wastewaters. The wastewater used in the experimental setup was a 3000-gallon batch taken from RAAP's Nitrocellulose Boiling Tub Pit. Acid concentrations were as shown in Table 1. The experiment using a process evaluation bench scale model with a single spiral-wound module was designed as noted in Figure 1. No pretreatment, such as pH adjustment, was attempted, nor was it deemed necessary to filter the water prior to the RO process. Concurrently with the in-house work being conducted at USAMERDC, a contract was awarded to the Direct Energy Conversion Division, General Electric Company, Lynn, Massachusetts to constitute, cast, and fabricate modified sulfonated polyphenylene oxide (SPPO) RO membranes which in previous G.E. work had indicated favorable resistance to low pH environments. Time framings on both efforts were such that July 1974 was estimated for on-site pilot plant studies (at RAAP) to confirm findings obtained in the laboratories. The scale of the pilot plant operations was designed to be approximately 1000 gallons per day (gpd) product water.

Table 1. Acid Composition of Wastewater from Nitrocellulose Area — Boiling Tub Pit Radford Army Ammunition Plant*

Concentration (ppm)		
Nitrates (NO_3)	Sulfates (SO_4)	pH
3200	5400	1.4

*Collected July 1973

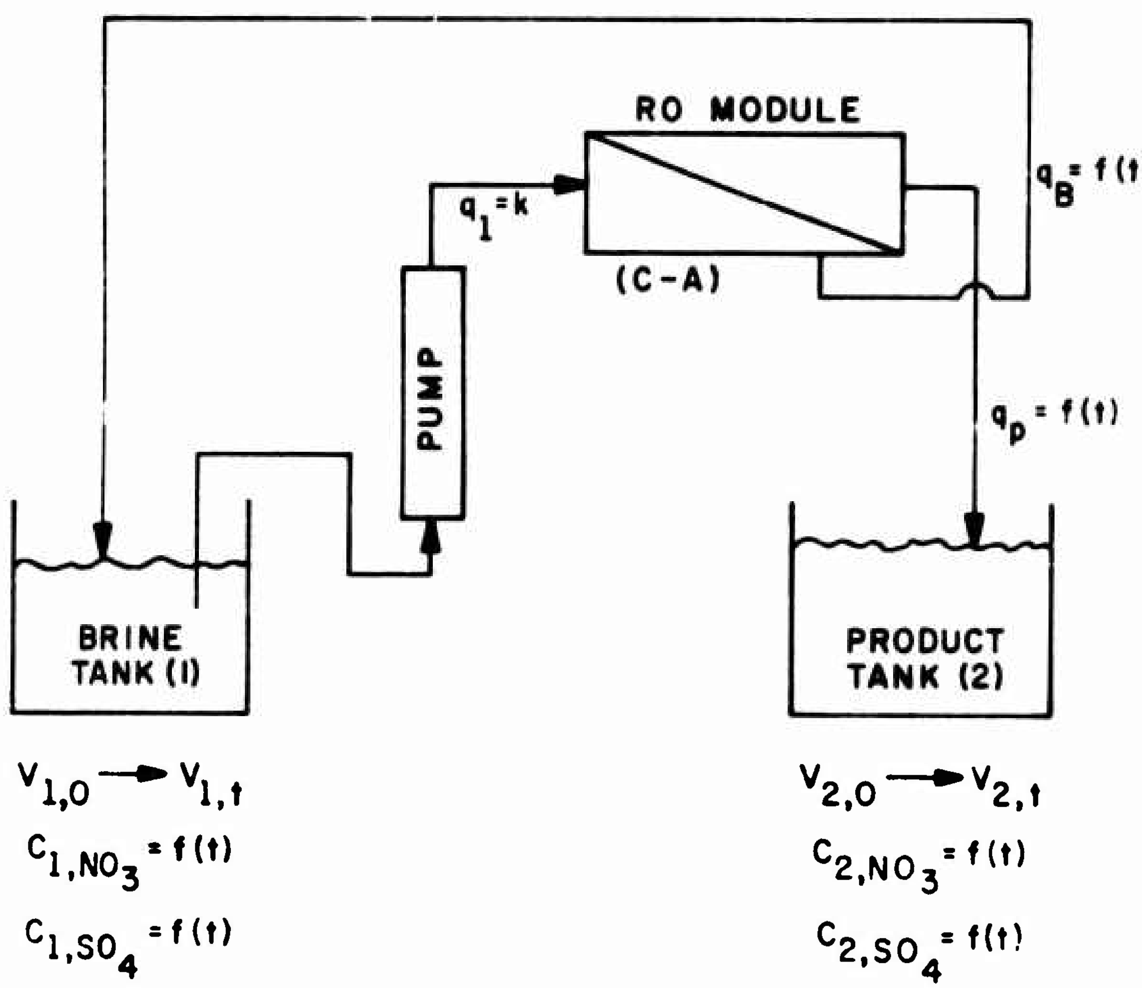


Figure 1. Simplified schematic flow diagram for laboratory setup.

The modeling mathematics of the experiment are detailed in Appendix A. This model was subsequently coded in FORTRAN by the Analysis & Programming Division (USAMERDC) for use on USAMERDC's CDC 6600 digital computer. The program appears as Appendix B. Output is available in the printed mode and as CALCOMP plots and prints.

All sample collection and chemical analyses were accomplished by personnel of the SSD, USAMERDC. Nitrate determinations were made using a nitrate specific ion electrode probe in conjunction with an expanded scale meter. Sulfate concentrations were determined using a Hach DR/2 spectrophotometer and the turbidimetric method found in APHA Standard Methods, 13th edition.

4. **Results.** The observed data for this phase of the project are shown in Tables 2 through 6. Nitrate concentrations are designated as IMPURITY 1, sulfates as IMPURITY 2. The product flow rate is reported in Table 6, where the change in volume of the product tank is measured as a function of time. The collected data were analyzed and plotted using computer curve fitting techniques and programs. Calcomp plots were produced and are shown as Figures 2 through 4.

A second-order polynominal curve was used as the data fitting model for the data reported in Tables 2 through 6. The statistical parameters associated with these fits were calculated and are reported in the computer printout attached as Appendix C.

Calculated engineering design parameters, based on second-order curve fits to the observed data, are shown in Table 7.

Calculated flux rates as a function of time are shown in Table 8 and the cartesian coordinate graph of these values in Figure 8.

The observed data as reported by General Electric Company regarding the modified SPPO membrane performance are shown in Table 9.

Figure 5 shows typical acid wastewater as generated at RAAP.

Figure 6 shows a typical section of cellulose acetate RO membrane cut from the actual module used in this study.

Figure 7 shows a typical 2-inch-diameter SPPO RO module mounted on a bench scale experimental setup.

Table 2. Impurity No. 1 (Nitrates), Brine Tank Concentration vs Time*

Time (hr)	Nitrates Conc. (ppm) Run No. 1	2	3	4	5
0	2080	2550	2330	2500	2180
2	2080	2500	2310	**	**
4	2030	2460	2360	2420	**
6	2027	**	2190	**	**
8	*	2490	2200	2280	**
10	*	**	2160	**	**
12	**	**	2175	2290	**
14	**	**	2155	**	**
16	**	2320	1990	2190	**
18	**	**	**	1825	**
20	**	2160	1700	**	**
22	**	*	*	1495	**
24	**	*	*	*	**
26	*	*	*	*	1310

*Cellulose-acetate membrane.
**No data collected at this point.

Table 3. Impurity No. 2 (Sulfates), Brine Tank Concentration vs Time*

Time (hr)	Sulfates Conc. (ppm) Run No. 1	2	3	4	5
0	3800	5900	5800	6400	6300
2	4100	6300	6500	**	**
4	5600	6200	6600	6900	**
6	5800	**	8500	**	**
8	*	6600	8500	7900	**
10	**	**	9000	**	**
12	**	**	9600	9100	**
14	**	**	8800	**	**
16	**	9800	9000	11,000	**
18	**	**	**	14,000	**
20	**	12,000	10,500	**	**
22	**	*	*	17,000	**
24	**	*	*	*	**
26	*	*	*	*	17,500

*Cellulose-acetate membrane.
**No data collected at this point.

Table 4. Impurity No. 1 (Nitrates), Product Tank Concentration vs Time*

Time (hr)	Nitrates Conc. (ppm) Run No. 1	2	3	4	5
0	0	0	0	0	0
2	2180	2700	2590	**	2180
4	2170	2730	2610	2850	**
6	2028	**	2720	**	**
8	*	2800	2670	2850	**
10	**	**	2640	**	**
12	**	**	2650	2720	**
14	**	**	2640	**	**
16	**	2750	2600	2840	**
18	**	**	**	2790	**
20	**	2860	2210	**	**
22	**	*	*	2770	**
24	**	*	*	*	**
26	*	*	*	*	2930

*Cellulose-acetate membrane.
**No data collected at this point.

Table 5. Impurity No. 2 (Sulfates), Product Tank Concentration vs Time*

Time (hr)	Sulfates Conc. (ppm) Run No. 1	2	3	4	5
0	0	0	0	0	0
2	300	700	500	**	**
4	200	400	460	680	**
6	200	**	480	**	**
8	*	600	470	620	**
10	**	**	510	**	**
12	**	**	560	820	**
14	**	**	540	**	**
16	**	480	500	850	**
18	**	**	**	800	**
20	**	550	690	**	**
22	**	*	*	950	**
24	**	*	*	*	**
26	*	*	*	*	1750

*Cellulose-acetate membrane.
**No data collected at this point.

Table 6. Volume in Product Tank vs Time

Time (hr)	Volume in Gallons				
	Run No.				
	1	2	3	4	5
0	0	0	0	0	0
2	22.5	23.8	61.0	**	25.0
4	45.0	45.0	88.0	35.0	**
6	57.5	**	104.0	**	**
8	*	70.0	119.0	85.0	**
10	**	**	144.0	**	**
12	**	**	163.0	121.0	**
14	**	**	182.0	**	**
16	**	145.0	198.0	160.0	180.0
18	**	**	**	200.0	211.0
20	**	185.5	240.0	**	237.0
22	*	*	*	235.0	242.0

* Cellulose-acetate membrane.
** No data collected at this point.

Table 7. Calculated Values for Engineering Design Parameters*

(Based on second-order curve fits)

Parameter	Time (hr) 0	Time (hr) 20	Remarks
Volume 1 (gallons)	345	125*	Brine Tank
Volume 2 (gallons)	0	212	$V_2 = -.13t^2 + 13t + 3.5$ Product Tank
CSO_4	5640	11096	$CSO_4 = 13t^2 + 11t + 5676$ Brine Tank
CNO_3 (ppm)	2330	1860	$CNO_3 = -2t^2 + 19t + 2280$ Brine Tank
CSO_4	5640	500**	Product Tank
CNO_3 (ppm)	0	2535**	
pH	1.3**	1.0**	Brine Tank
pH	0	1.6**	Product Tank

* Cellulose-acetate membrane.
** As observed and recorded - average value.

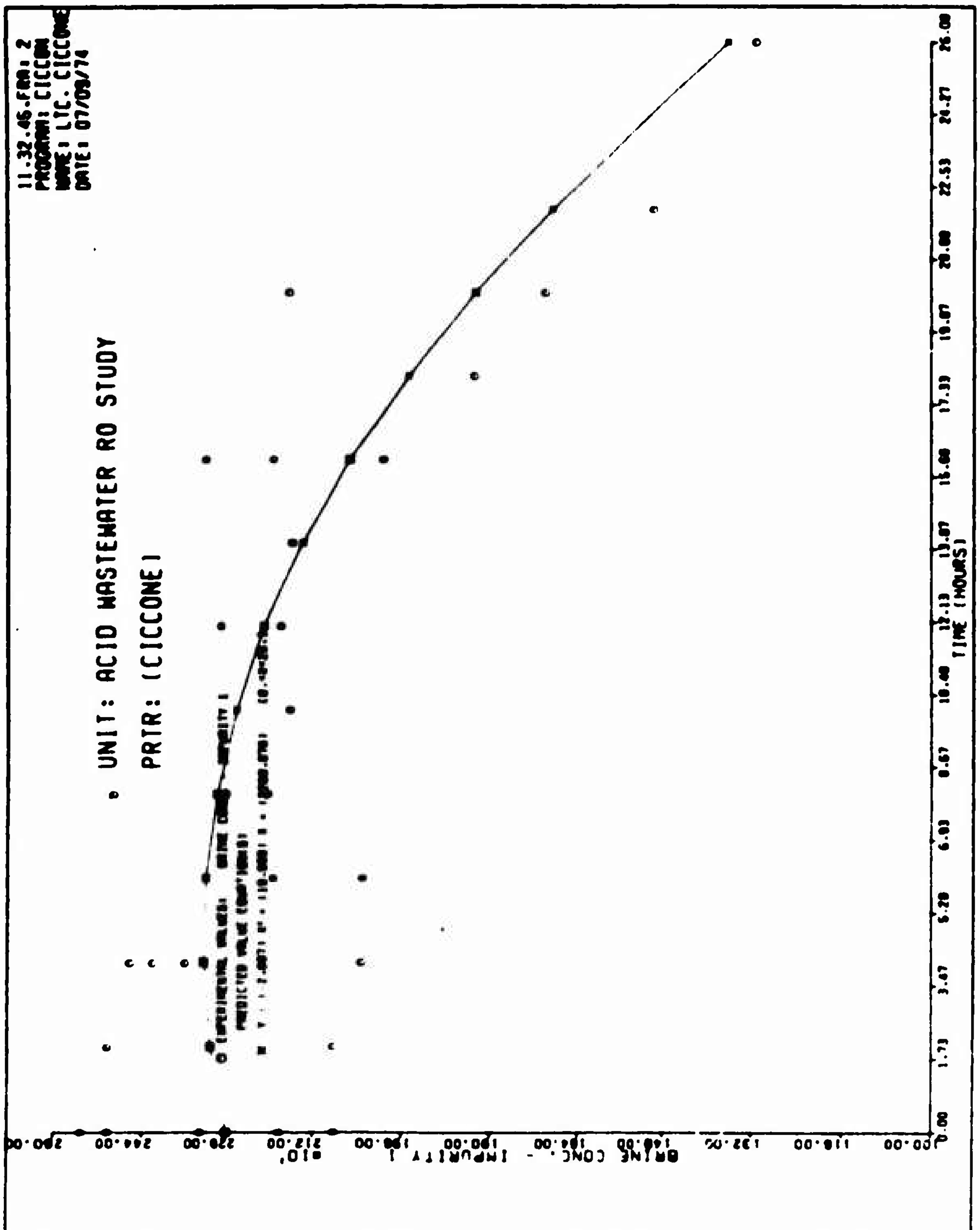


Figure 2. Concentration of nitrates in brine tank vs time.

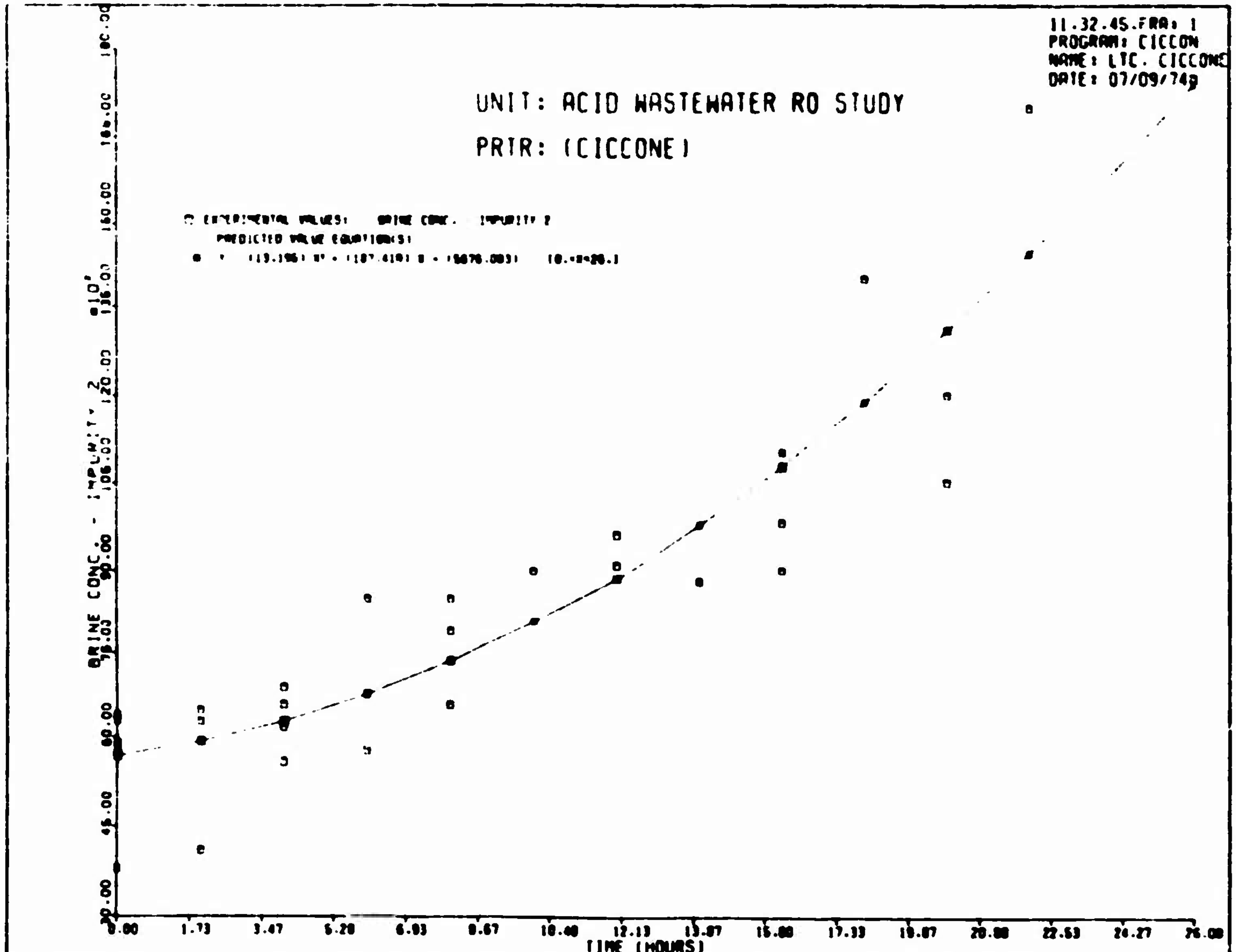


Figure 3. Concentration of sulfates in brine tank vs time.

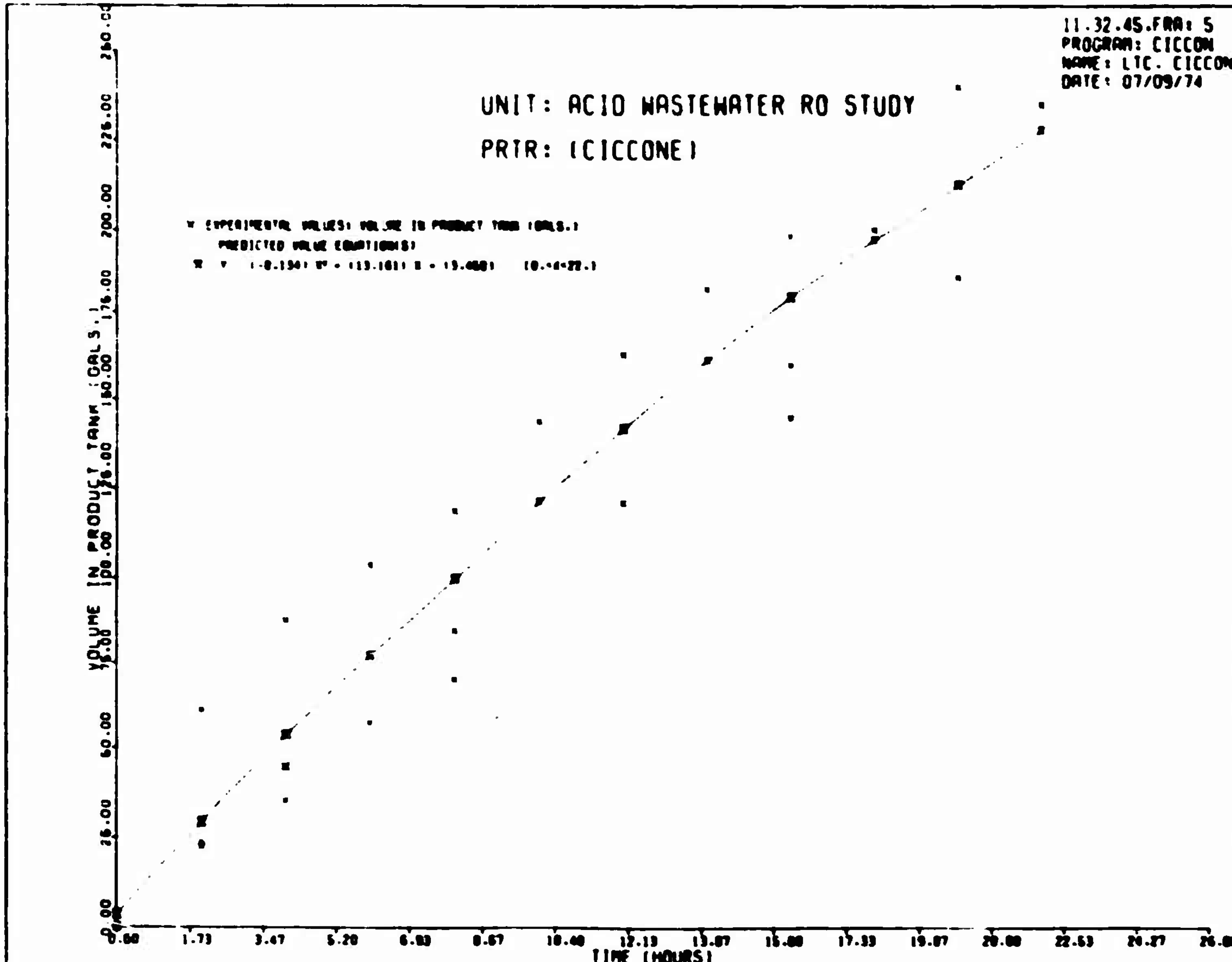


Figure 4. Volume in product tank vs time.

Table 8. Calculated Module Production Rate
(gph & GF^2D)
(Based on Second-Order Fitted Curve)

$$V_2 = -0.13t^2 + 13t + 3.5$$

$$\frac{dV_2}{dt} = -0.26t + 13$$

Time	Production Rate	
(hr)	gph	GF^2D*
0	13.00	9.49
2	12.50	9.13
4	11.96	8.73
6	11.44	8.35
8	10.92	7.97
10	10.40	7.59
12	9.88	7.21
14	9.36	6.83
16	8.84	6.45
18	8.32	6.07
20	7.80	5.70

*Module surface area = 33 S.F.

Table 9. Modified Sulfonated Polyphenylene Oxide Membrane Evaluation

	Performance*		
Membrane Sample No.	Test Time (hr)	Flux (GF^2D)	Rejection (%)
1	24	30	87
2	20	11	90
3	17	12	90

Experimental Conditions Were:
Feed: 3000 ppm acid (2000 H_2SO_4, 1000 HNO_3)
Press: 600 psi
Temp: 74°F - 80°F

* As reported by General Electric Co. under Contract DAAK02-73-C-0407 with USAMERDC.

Figure 5. Typical acid wastewater from RAAP.

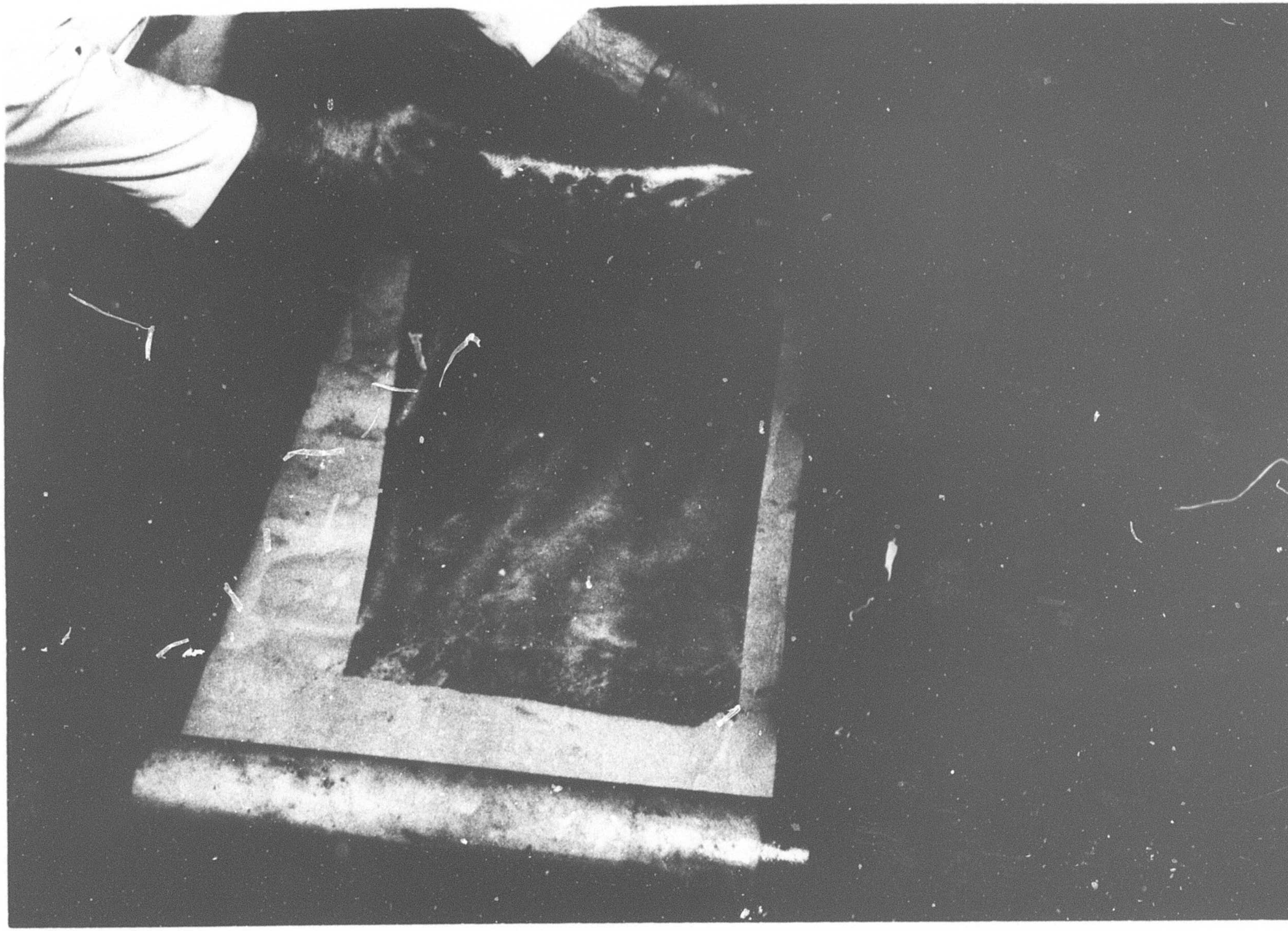


Figure 6. Typical section of cellulose acetate RO membrane after exposure to acid wastewater.

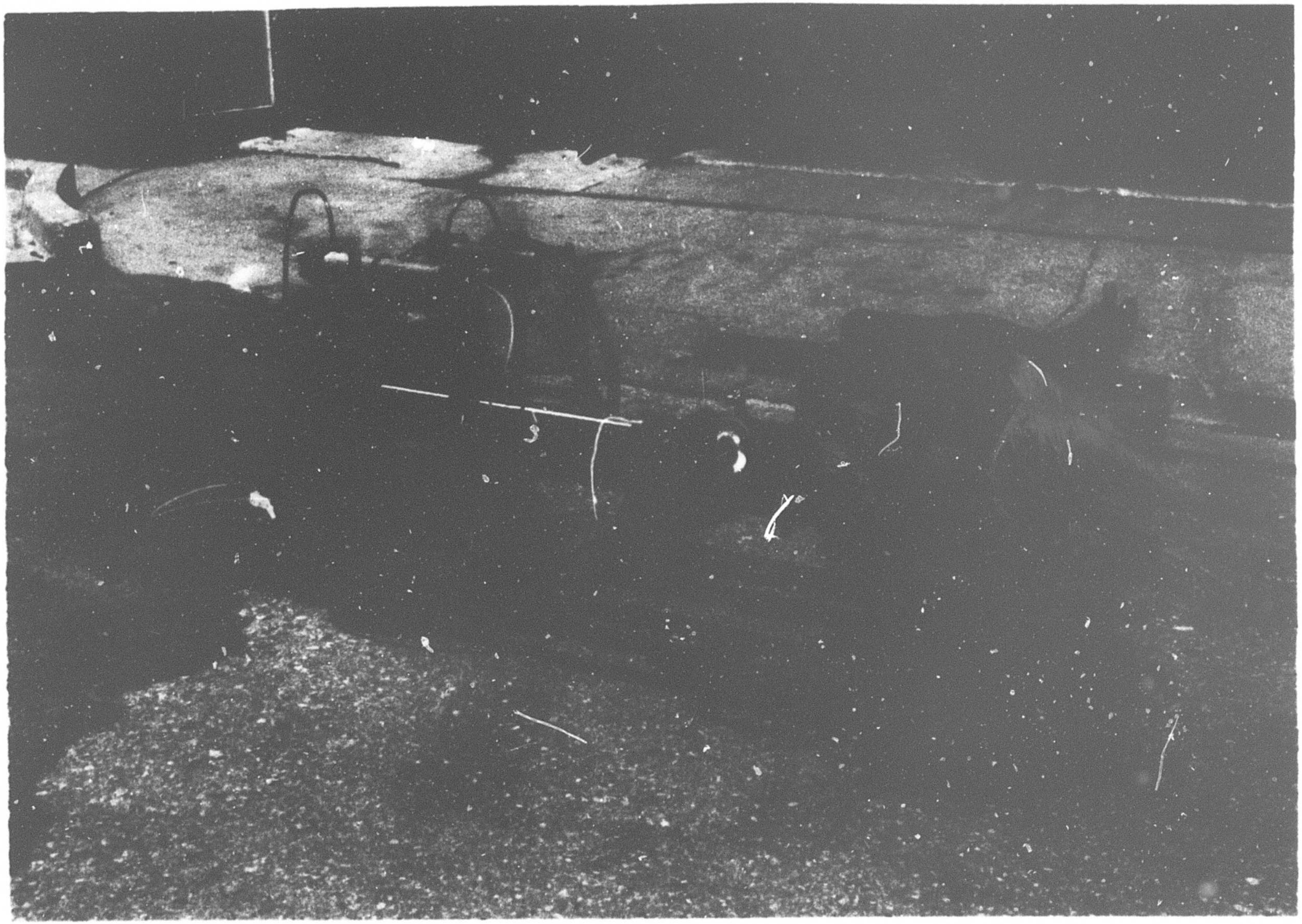


Figure 7. Typical 2-inch-diameter SPPO module – in bench scale setup.

III. DISCUSSION

5. **Discussion.** The cellulose acetate membrane experiment described earlier was designed to yield data which could be representative of the module behavior with respect to its ability to reject both acid species and to establish its water production or flux rate. The five runs, as noted in Tables 2 through 6, essentially were deserete repetitions of the same experiment. An objective in producing these data was to structure it into a form which could be acceptable for engineering design of a larger scaled-up system. The second-order curves obtained provide these engineering design data when considering the rate at which the acid species are being affected. Figures 2 and 3 show the nitrate and sulfate concentrations in the brine tank as functions of time. The rates at which these are changing with respect to time are easily obtained by taking the first derivative of the fitted curve; i.e., dC/dt. In this manner, the rates may be computed for any point in time within the bounds of the experiment. Since we are ultimately interested in designing a fullscale plant, practicality dictates that operation stay within a 24-hour period. Hence, the upper bond on the curve is valid (i.e., less than 24 hours) and differentiation of the curve within these time limits yields rates which may be interpreted as truly indicative of the module performance. This technique when applied to the pemeate or flux rate (i.e., dV_2/dt, Figure 4) of the module integrates the rate over time, giving a more accurate estimate of this variable as compared to a grab sampling manner of estimation. It is noted in this case that flux rate may be described as an unsteady rather than a steady state condition, and hence time averaging or smoothing is necessary to account for the inherent variations. Given this derived empirical equation, one may then estimate flux at any given point over the time horizon of interest; i.e., within a 24-hour period. Simultaneously, the rate of concentration (or loss) of the particular acid species may also be calculated.

Table 7 shows the calculated values for the parameters of interest, after a 20-hour continuous run, for a single RO spiral-wound module. This performance behavior was encouraging, especially in light of the pH values. Hydrolysis of the membrane is a potential failure mode, and it was expected by this investigator that hydrolysis would occur. A rapid means of detecting gross hydrolysis was used throughout the data collection phase. This involved rinsing the module with tap water and determining the total dissolved solids (TDS) values of the inlet, product, and retentate streams using a dissolved solids meter. In each case, the reported TDS rejection rate was recorded at (on the average) approximately 90 percent. This indicated that gross hydrolysis had not occurred. A possible explanation for this favorable behavior may lie in part in the operational mode followed throughout the experiment. That is, after approximately every 8 hours of continuous operation, a short period of fresh water flushing was accomplished, which in effect tended to modify the membrane pH—a critical condition for hydrolysis to occur. To assume that the membrane pH is consistent with that of the brine or permeate fluids

is not necessarily correct. This assumption needs further verification and its documentation is beyond the scope of this work. The data observed here indicate that there may be an inconsistency in the membrane-fluid pH relationship or that at least a time-reaction element condition exists and it plays a significant role in that relationship.

In reviewing the production or flux rates of the module, evaluating the variable dV_2/dt for selected t values gives an indication of the commonly observed classical "fouling" behavior. The exact mechanism or cause for this phenomenon will not be pursued here, but suffice it to say that the primary cause was believed to be colloidal materials and ferric oxides. The colloidal materials may have been present in the original wastewaters, while the iron oxides may have originated within the experimental system due to the corrosive activity of the acids upon the metallic components of the setup. In any case, the noteworthy item is that Figure 8 is representative of statistically analyzed values which indicate the recoverability of the flux after repeated experiments or exposures. That is, the function may be interpreted as being a predictor for a reversible type degradation of flux overtime (20 hours) when the operational mode includes periodic flushing with a fresh water. Given this empirical "engineering data" and that shown in Table 7, the problem of a properly designed RO system capable of treating acid wastewaters can be approached with an encouraging degree of confidence.

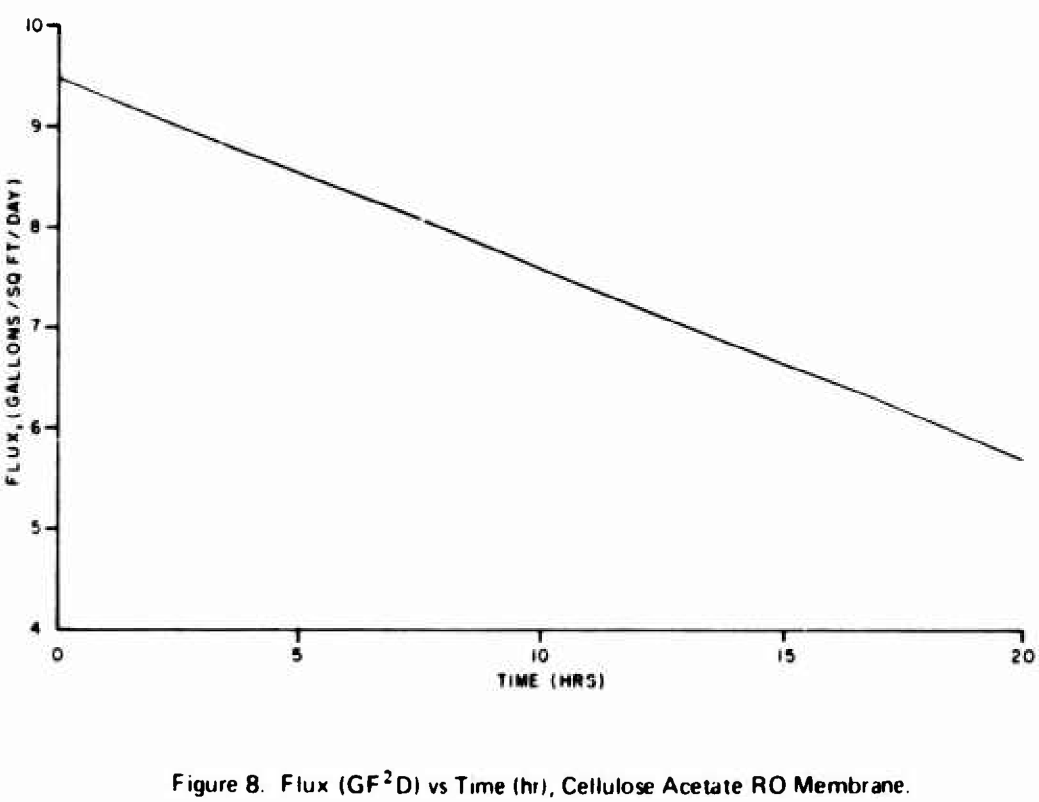


Figure 8. Flux (GF^2D) vs Time (hr), Cellulose Acetate RO Membrane.

The data presented on the SPPO membranes (Table 9) showing the flux and rejection rates, although not given the type of analysis as that shown for the cellulose acetate, appear to be most enlighting. It is noted that significant progress has been made in the G.E. contract. Formulating, casting, and the fabricating of spiral-wound modules has been completed for extensive testing in the scaled-up pilot plant operation noted earlier. During this next phase, rigorous exposure and analysis of the observed data will be accomplished on both these SPPO and other cellulose-acetate spiral-wound RO modules. Therefore, further discussion regarding the SPPO membrane is postponed until completion of the next phase of the project.

IV. CONCLUSIONS

6. **Conclusions.** Based on the data obtained in the laboratory phase of this study and subject to that data generated in the pilot plant phase, the following conclusions appear valid:

a. The application of cellulose-acetate and modified sulfonated polyphenylene oxide RO membranes as a unit process in the treatment of dilute acid wastewaters generated at RAAP is technically feasible.

b. The concentration of nitric and sulphuric acid at acceptable rates for engineering scale-up using RO is feasible and attainable.

c. The permeation or flux rates attainable in the treatment of RAAP acid wastewaters are acceptable for engineering scale-up.

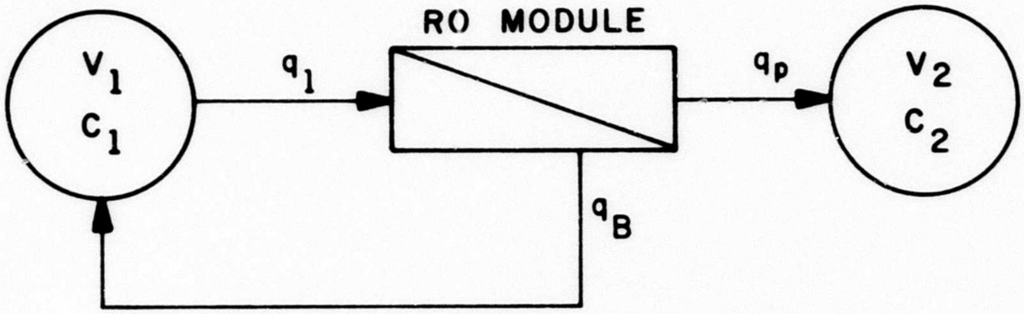
d. Hydrolysis of the cellulose-acetate membrane did not significantly impair the performance characteristics of the RO modules.

e. Acidic corrosion of the metallic components of the RO system can introduce operational problems that will significantly interfere with the rejection and flux rates of the RO membranes.

f. Continuation of the program into a Phase II RO pilot plant operation located at RAAP for on-site evaluation and performance documentation and/or verification is justified.

APPENDIX A

REJECTION MODEL MATHEMATICS



Definitions:

V_1 = fluid volume in tank 1

V_2 = fluid volume in tank 2

C_1 = concentration in tank 1

C_2 = concentration in tank 2

q_1 = fluid flow rate in $- \frac{dV_1}{dt} = K$

q_p = product flow rate = $\frac{dV_2}{dt}$

q_B = brine flow rate

t = time

$C_{10} = C_1$ at t=0

$V_{10} = V_1$ at t=0

α = rejection percentage rate

Consider Single Species Only

balance on 1 is:

(1) $q_1 * C_1 = V_1 C_1 - q_p * C_1 + q_B (1 - \alpha) C_1$

balance on 2 is:

(2) $q_p * C_2 = q_1 * C_1 - q_1 * \alpha * C_1$

(2a) $\frac{d}{dt} V_2 * C_2 = KC_1 - K \alpha C_1$

from continuity: $q_1 = q_p + q_B$ (3)

$V_1 + V_2 = V_{10}$ (4)

Overall balance on the system:

$C_1 V_1 + C_2 V_2 = C_{10} V_{10}$ (5)

$C_1 = \frac{C_{10} V_{10} - C_2 V_2}{V_{10} - V_2}$ (6)

Now differentiate (2a) and obtain

(2b) $V_2 \frac{dC_2}{dt} + C_2 \frac{dV_2}{dt} = KC_1 - K \alpha C_1$

(2c) $= KC_1 (1 - \alpha)$

Substitute (6) into (2c)

$$V_2 \frac{dC_2}{dt} + C_2 \frac{dV_2}{dt} = K \left[\frac{C_{10} V_{10} - C_2 V_2}{V_{10} - V_2} \right] \left[1 - \alpha \right]$$

Let $\Delta = V_{10} - V_2$

$$\alpha_T = 1 - \left[\frac{C_2}{K[\Delta]} * \frac{dV_2}{dt} \right] - \left[\frac{V_2}{K[\Delta]} * \frac{dC_2}{dt} \right]$$

FORTRAN PROGRAM – REJECTION MODEL

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PROGRAM CICCONE    74/74    OPT=1                    FTN 4.1+PSR367      07/09/74  11.25.14.       PAGE    1

      PROGRAM CICCONE(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT,TAPE3,TAPE4)
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      COMMON/YINP/LENY(9),YINP(500,9)
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      COMMON/DERIVA/YPRE(500,6),XPRE(500),LPRE,DVOLCON
      DIMENSION STATS(8)
      DIMENSION CC(11)
      DIMENSION Y(500),YL(500),P(500),R(500),YP(500),RES(500),XDUM(500)
      DIMENSION SSR(5),B(2),AINV(4),C(4),S(2),IBUF(1000)
      DIMENSION MWHCH(2)
      DATA MWHCH(1),MWHCH(2)/8,4/
      DATA ISWT/1/
      DATA (X(I,1),I=1,500)/500*1.0/
C
C THIS PROGRAM IS AN EXPONENTIAL CURVE FIT USING REGRESSION ANALYSIS
C N IS NUMBER OF OBSERVATIONS
C
C
C     INPUT SECTION
C CARD              INPUT DECK STRUCTURE
C  1  MONT,DAY,YEAR,CYCLE      (A5,3F10.4)
C        MONT  CENTERED 7 CHARACTER MONTH ABBREVIATION
C        DAY,YEAR,CYCLE   APPROPRIATE NUMBERS
C  2  30 CHARACTER UNIT TITLE    (3A10)
C  3  30 CHARACTER PRETREATMENT DESCRIPTION    (3A10)
C  5 IPLOT,IMODL   (2I2)   01..YES PLOT,02..NO PLOT,   00..NO MODEL, 01..YES MODEL
C  6  XMAX,AXLEN(REJ),YMIN(REJ),YMAX(REJ),AXLEN(FLUX),YMIN(FLUX),YMAX(FLUX)
C                         (7F10.4)
C        XMAX  MAXIMUM EXPECTED CUMULATIVE TIME
C        AXLEN  INCHES DESIRED FOR THE Y AXIS,  MAXIMUM IS 10.
C        YMIN  LEAST Y VALUE
C        YMAX  GREATEST Y VALUE
C  7  NUMBER OF X DATA POINTS    (I5)
C 8-A  N  -  X DATA POINTS    (F10.4)
C          THE ENTIRE SET OF CUMULATIVE TIME DATA IS READ HERE
C  B  IXWHCH,ISEGNU,ICONT,IXSRT,M,ICURVE     (6I5)
C        IXWHCH  01..TURBIDITY-COAG,  02..TURBIDITY-FILTER..SPECIFIES KIND OF DAT
C        ISEGNU  SEGMENT NUMBER USED IN KEY
C        ICONT   01..THIS DATA IS NOT THE LAST Y SET CORRESPONDING TO X
C                02..GET THE NEXT X DATA SET AFTER PROCESSING THIS Y DATA SET
C        IXSRT   ARRAY INDEX OF FIRST X CORRESPONDING TO THE FIRST Y OF THIS
C                SEGMENT
C        M  NUMBER OF Y DATA POINTS IN THIS SEGMENT
C        ICURVE  01..EXPONENTIAL FIT, 02..POLYNOMIAL CURVE FIT
C        IORD IS THE ORDER OF THE POLYNOMIAL
C  C  NUGRAF,NUAXIS    (2I5)
C        NUGRAF  01..PUT THIS DATA ON A NEW FRAME, 02..SAME FRAME
```

```
C          NUAXIS  =1..DRAW A NEW Y AXIS, =2.. STAY ON THE OLD AXIS
C  D  M  -  Y DATA CARDS    (F10.4)
C  DD  XTIL,YTIL,TMAG,XKEY,YKEY,RKMAG      (6F10.4)
C          THIS CARD IS ONLY NECESSARY AFTER A NEW FRAME HAS BEEN REQUESTED
C          XTIL,YTIL,TMAG  SIZE AND LOCATION OF TITLE HEADING
C          XKEY,YKEY,RKMAG  SIZE AND LOCATION OF THE GRAPH KEY AND LINE EQUATIONS
C  E  SEGMENT DATA SETS CONSIST OF CARDS B,C,D, AND POSSIBLY DD
C  F  COMPLETE DATA SET CONSISTS OF CARDS 2,3,4,5,6,7,8,A, AND ANY E SETS
C     COMPLETE RUN SET REQUIRES CARD 1 AT THE TOP
C
      MONT=SHIFT(DATE(IJ),6)
      ITIME=SHIFT(TIME(IJ),6)
      WRITE(4,300)
300    FORMAT(1H1)
C     READ IN THE AXIS TITLES
      DO 120 I=1,5
      READ(1,121) (XTITLE(J,I),J=1,4)
121   FORMAT(4A10)
      IF(EOF(1)) 500,120
120   CONTINUE
500   CONTINUE
      DO 122 I=1,10
      READ(1,121) (YTITLE(J,I),J=1,3)
      IF(EOF(1)) 501,122
122   CONTINUE
501   CONTINUE
61    CALL READIN,RETURNS(97,99)
97    GO TO (42,101),IFLOT
42    GO TO (40,101),ISWT
40    ISWT = 2
C
C     OPEN THE PLOT TAPE IF REQUESTED
C
130   IDARKB = 6
      IDARKT = 4
      IDARKP = 2
      CALL CALCMP(IBUF,1000,3,0)
      CALL CALCMP(0.,0.,IDARKB,3)
      CALL BORDER(0.,0.,17.,11.)
      CALL CALCMP(0.,0.,IDARKT,3)
      CALL IDFRAM(6.,4.5,.28)
      CALL CALCMP(14./17.,8./11.,IDUM,4)
101   CONTINUE
50    READ(1,22) IXWHCH,IYWHCH,IXSRT,IYSRT,ICURVE,IORD,N,ISEGNU,ICONT
     1,NXTRP
22    FORMAT(16I5)
      IF(EOF(1)) 61,9191
9191  CONTINUE
      IF(N.EQ.0 .AND. IXSRT .NE. 0) N=LENX(IXWHCH)-IXSRT+1
      IF(N.EQ.0 ) N=LENX(IXWHCH)
      IF(IXSRT.EQ.0) IXSRT=1
      IF(IYSRT.EQ.0) IYSRT=1
      IF(ISEGNU.EQ.0) ISEGNU=1
      IF(ICONT.EQ.0 ) ICONT=1
      READ(1,22) NUGRAF,NUSYTS
      IF(EOF(1)) 99,9292
9292  CONTINUE
```

```
            IFRAME=FRAME
            IF(NUGRAF.EQ.1)  IFRAME=IFRAME+1
            DO 15 I=1,N
            Y(I)=YINP(IYSRT+I-1,IYWHCH)
            IF(ICURVE.EQ.1) YL(I)=ALOG(Y(I))
   15       X(I,2)=XINP(IXSRT+I-1,IXWHCH)
            CALL BUS(Y,N,STATS)
C
C    MRA IS A MULTIPLE REGRESSION ANALYSIS ROUTINE
C
C    USE QUANTITIES JUST CALCULATED TO COMPUTE PREDICTED Y
C
            D=N-2.
            MNXTRP=0
            DLXTRP=0.
            GO TO (23,24),ICURVE
   23       CALL MRA(X,N,2,5C,YL,D,F,SSR,B,F,P,AINV,C,2,S)
            B(1) = EXP(B(1))
            DO 25 J=1,N
            YP(J) = B(1)*EXP(X(J,2)*B(2))
            RES(J)=Y(J)-YP(J)
   25       CONTINUE
            NCURVE(IYWHCH)=1
            COEFFS(IYWHCH,1)=B(1)
            COEFFS(IYWHCH,2)=B(2)
            GO TO 26
   24       IF(IORD.EQ.0) IORD = 1
            CALL POLYFIT(X,Y,N,IORD,YP,RES,CC,SSR)
            NCURVE(IYWHCH)=2
            NORDER(IYWHCH)=IORD
            NAP=IORD+1
            DO 75 J=1,NAP
   75       COEFFS(IYWHCH,J)=CC(J)
C
C           THIS IS THE SECTION THAT EXTRAPOLATES BEYOND THE DATA
C
   26       IF(MNXTRP.EQ.0) GO TO 267
            READ(1,261) MNXTRP,DLXTRP
  261        FORMAT(I10,F10.4)
            DO 262 MMXTR=1,MNXTRP
  262       X(N+MMXTR,2)=X(N+MMXTR-1,2)+DLXTRP
            GO TO (263,264),ICURVE
  263       DO 265 MMXTR=1,MNXTRP
  265       YP(N+MMXTR)=COEFFS(IYWHCH,1)*EXP(X(N+MMXTR,2)*COEFFS(IYWHCH,2))
            GO TO 25
  264       ITOP=IORD+1
            DO 266 MMXTR =1,MNXTRP
            EXTSUM=0.0
            DO 267 MMMXTR=1,ITOP
  267       EXTSUM=EXTSUM+COEFFS(IYWHCH,MMMXTR)*(X(N+MMXTR,2)**(ITOP-MMMXTR))
  266       YP(N+MMXTR)=EXTSUM
   26       WRITE(2,2)
            WRITE(2,3)
   88       CONTINUE
            WRITE(2,75) MONT,TTIME,IFRAME
            WRITE(6,301)
  301        FORMAT(//)
```

```
      WRITE(4,35) MONT,ITIME,IFRAME
35    FORMAT(T6,*DATE *,A10,*  TIME *,A10,*   FRAME NO. *,I4)
      WRITE(4,43) IXWHCH,IYWHCH,IXSRT,IYSRT,ICURVE,IORD,N,ISEGNU,ICONT
     3,NUGRAF,NUAXIS
43    FORMAT(* IXWHCH *,I5,*  IYWHCH *,I5,*  IXSRT *,I5,*  IYSRT *,I5,
     3*  ICURVE *,I5,
     1*  IORD *,I5/*  N *,I5,*  ISEGNU *,I5,*  ICONT *,I5,*  NUGRAF *,I5
     2,*  NUAXIS *,I5)
      WRITE(2,36) IUNIT
36    FORMAT(T6,4A10)
      WRITE(2,36) IPRTP
      WRITE(4,39) XMIN(IXWHCH),XMAX(IXWHCH),YMIN(IYWHCH),YMAX(IYWHCH),XL
     1EN(IXWHCH),YLEN(IYWHCH),DELTAX(IXWHCH),DELTAY(IYWHCH)
39    FORMAT(*  XMIN *,F10.4,*  XMAX *,F10.4,*  YMIN *,F10.4,*  YMAX *,F
     110.4/
     1     *  XLEN *,F10.4,*  YLEN *,F10.4,*  DELTAX *,F10.4,*  DELTAY *
     2,F10.4)
      WRITE(2,34) (XTITLE(JJ,IXWHCH),JJ=1,4),(YTITLE(KK,IYWHCH),KK=1,3)
34    FORMAT(1X,4A10,*  VS  *,3A10/T3,* X VALUE*,T15,*   Y VALUE  *,T29,
     1*PREDICT Y VALUE*,T45,*RESIDUAL*)
33    WRITE(2,5) (X(I,2),Y(I),YP(I),RES(I),I=1,N)
      IF(NXTRP.NE.0) WRITE(2,268)(X(N+I,2),YP(N+I),I=1,MNXTRP)
268   FORMAT(1H ,1X,F8.1,23X,F8.1)
      WRITE(2,6) N
      IF(NXTRP.NE.0) WRITE(2,269) MNXTRP,DLXTRP
269   FORMAT(*  NUMBER OF EXTRAPOLATED POINTS IS *,I5,2X,*EVERY *,F10.4,
     1* UNITS*)
      GO TO (28,29),ICURVE
28    WRITE(2,9) SSR(1)
      WRITE(2,10) SSR(2)
      WRITE(2,11) SSR(3)
      WRITE(2,12) SSR(4)
      WRITE(2,13) B
13    FORMAT(1H0,2X,*EQUATION IS OF THE FORM Y = A EXP(B X) WHERE A = *,
     1E15.6,3X,*AND B = *,E15.6)
      GO TO 30
29    WRITE(2,12) SSR(4)
      WRITE(2,14)
14    FORMAT(1H0,2X,54HEQUATION IS OF THE FORM Y = C(1)*X**IORD+...+C(IO
     1RD+1))
      DO 201 I=1,IORD
      IDIND = IORD-I+1
      IF(IDIND.EQ.1) GO TO 205
      WRITE(2,200)CC(I),IDIND
200   FORMAT(* WHERE Y =*,(T11,3H + ,E15.6,6H *X** ,I2))
      GO TO 201
205   WRITE(2,206)CC(I)
206   FORMAT(T11,3H + ,E15.6,3H *X)
201   CONTINUE
      WRITE(2,202)CC(IORD+1)
202   FORMAT(T11,3H + ,E15.6)
    1 FORMAT(F10.0)
    2 FORMAT(1H1,T6,*SANITARY SCIENCE DIVISION REVERSE OSMOSIS*)
    3 FORMAT(1H ,T20,*DATA ANALYSIS*)
    4 FORMAT(1H0,T3,*CUM MINS*,T15,*TURBID(COAG)*,T29,*PREDICT T-COAG*,
     1 T45,*RESIDUAL*)
    5 FORMAT(1H ,1X,F8.1,6X,F8.1,9X,F8.1,6X,F9.1)
```

```
    6 FORMAT(1H0,2X,*NUMBER OF OBSERVATIONS IS*,I4)
    9 FORMAT(1H0,2X,*SS OF RESIDUALS IS*,21X,E15.6)
   10 FORMAT(1H0,2X,*SSY ABOUT MEAN IS*,22X,E15.6)
   11 FORMAT(1H0,2X,*ESTIMATE OF ERROR VARIANCE IS*,10X,E15.6)
   12 FORMAT(1H0,2X,*SQ MULT CORR COEF IS*,19X,E15.6)
   30 WRITE(2,170) STATS
  170 FORMAT(/* BASIC STATISTICS ABOUT THE Y INPUT ARE *,
     1/* MEAN = *,G11.5,
     2/* SECOND MOMENT = *,G11.5,
     3/* THIRD MOMENT = *,G11.5,
     4/* FOURTH MOMENT = *,G11.5,
     5/* VARIANCE = *,G11.5,
     6/* STANDARD DEVIATION = *,G11.5,
     7/* SKEWNESS = *,G11.5,
     8/* KURTOSIS = *,G11.5/)
C
C     PLOTTING SECTION
C
      GO TO (104,109),IPLOT
  104 GO TO(109,72),NUGRAF
  109 READ(1,111) XTIL,YTIL,THAG,XKEY,YKEY,RKMAG
  111 FORMAT(5F10.4)
      WRITE(4,112) XTIL,YTIL,THAG,XKEY,YKEY,RKMAG
  112 FORMAT(    T6,*XTIL = *,F10.4,*  YTIL = *,F10.4,*  THAG = *,F10.4/
     1T6,*XKEY = *,F10.4,*  YKEY = *,F10.4,*  KMAG = *,F10.4)
   71 CALL CALCMP(0.,0.,IDARKB,3)
      CALL BORDER(0.,0.,17.,11.)
      CALL CALCMP(0.,0.,IDARKT,3)
      CALL IDFRAM(14.5,10.1,.14)
      CALL CALCMP(1.5,0.5,IDARKT,3)
      CALL AXIS(0.,0.,XTITLE(1,IXWHCH),-40,XLEN(IXWHCH),0.,XMIN(IXWHCH),
     *DELTAX(IXWHCH))
      CALL HEAD(XTIL,YTIL,THAG)
      XFSAX = 0.
   72 GO TO (73,74),NUAXIS
   73 CALL AXIS(XFSAX,0.,YTITLE(1,IYWHCH),30,YLEN(IYWHCH),90.,YMIN(IYWHC
     *H),DELTAY(IYWHCH))
      XFSAX = -.75
      CALL KEY(XKEY,YKEY,RKMAG,IYWHCH)
   74 RMAXY = YMAX(IYWHCH)
      RMINY = YMIN(IYWHCH)
      DO 76 I=1,N
      XDUM(I) = X(I,2)
      IF (XDUM(I) .GT. XMAX(IXWHCH)) XDUM(I)=XMAX(IXWHCH)
      IF(XDUM(I).LT.XMIN(IXWHCH)) XDUM(I)=XMIN(IXWHCH)
      IF (Y(I) .GT. RMAXY)  Y(I) = RMAXY
      IF (Y(I).LT.RMINY) Y(I) = RMINY
      IF (YP(I) .LT. RMINY) YP(I) = RMINY
   76 IF (YP(I) .GT. RMAXY)  YP(I) = RMAXY
      XDUM(N+1) = XMIN(IXWHCH)
      XDUM(N+2) = DELTAX(IXWHCH)
      Y(N+1)=YMIN(IYWHCH)
      Y(N+2)=DELTAY(IYWHCH)
      CALL CALCMP(1.5,0.5,IDARKP,3)
      CALL LINE(XDUM,Y,N,1,-1,IYWHCH-1)
      IF(NXTRP.EQ.0) GO TO 702
      DO 7 1 I=1,MNXTRP
```

```
      XDUM(I+N)=X(N+I,2)
      IF(XDUM(I+N).GT.XMAX(IXWHCH)) XDUM(I+N)=XMAX(IXWHCH)
      IF(XDUM(I+N).LT.XMIN(IXWHCH)) XDUM(I+N)=XMIN(IXWHCH)
      IF(YP(I+N).LT.RMINY) YP(I+N)=RMINY
  781 IF(YP(I+N).GT.RMAXY) YP(I+N)=RMAXY
      XDUM(N+MNXTRP+1) = XMIN(IXWHCH)
      XDUM(N+MNXTRP+2)= DELTAX(IXWHCH)
  782 YP(N+MNXTRP+1) = YMIN(IYWHCH)
      YP(N+MNXTRP+2) = DELTAY(IYWHCH)
      CALL LINE(XDUM,YP,N+MNXTRP,1,1,13-IYWHCH-ISEGNU)
      CALL CALCHP(1.5,8.5,IDARKT,3)
      CALL EQNDRA(XKEY+RKMAG,YKEY,RKMAG,B,XDUM(1),XDUM(N+MNXTRP),CC)
      YKEY = YKEY - .35
  105 GO TO (60,61,80),ICONT
C
C     THIS IS THE MODEL SECTION UNDER LTD CICCONES CARE
C
   80 READ(1,81) ISWD,IMPUR,DVOLCON,RK,TIM0,NOINC,TIMF
   81 FORMAT(2I5,3F10.4,I5,F10.4)
      WRITE(4,83) ISWD,IMPUR,DVOLCON,RK,TIM0,NOINC,TIMF
   83 FORMAT(* ISWD *,I5,* IMPUR *,I5,* DVOLCON *,F10.4,
     1* RK *,F9.4,* TIM0 *,F10.4,* NOINC *,I4,* TIMF *,F10.4)
      LPRE=NOINC+1
      XPRE(1)=TIM0
      DELT=(TIMF-TIM0)/NOINC
      DO 76 I=1,NOINC
   76 XPRE(I+1)=XPRE(I)+DELT
      CALL CALFQN(3)
      IF(IMPUR.EQ.2) GO TO 90
      CALL CALEQN(1)
      CALL DERIV(1)
      IF(IMPUR.EQ.1) GO TO 91
   90 CONTINUE
      CALL CALEQN(2)
      CALL DERIV(2)
   91 IF(ISWD.EQ.1) GO TO 92
      CALL DERIV(3)
      GO TO 93
   92 CONTINUE
      CALL DERIV(4)
   93 CONTINUE
      JSWT=1
      JJINR=NCURVE(7)
      GO TO (150,151),JJINR
  150 V10=COEFFS(7,1)*EXP(TIM0*COEFFS(7,2))
      GO TO 152
  151 JJORD=NORDEP(7)+1
      V10=0.
      DO 153 JJ=1,JJORD
  153 V10=V10+COEFFS(7,JJ)*(TIM0**(JJORD-JJ))
  152 CONTINUE
      IF(IMPUR.NE.3) GO TO 45
      JSWT=2
      IMPUR=1
      ILIM=NOINC+1
   45 MPOINT=MWHCH(IMPUR)
      JJINR=NCURVE(MPOINT)
```

```
      GO TO (162,163),JJINP
  162 C10=COEFFS(MPOINT,1)*EXP(TIME*COEFFS(MPOINT,2))
      GO TO 164
  163 JJORD=NORDEP(MPOINT)+1
      C10=0.
      DO 165 JJ=1,JJORD
  165 C10=C10+COEFFS(MPOINT,JJ)*(TIME**(JJORD-JJ))
  164 CONTINUE
      L=IMPUR+8
      DO 86 I=1,ILIM
      CONST=RK*(C10*V10-YPRE(I,IMPUR)*YPRE(I,3))/(V10-YPRE(I,3))
      Y(I)=( 1-(YPRE(I,IMPUR)/CONST*YPRE(I,6))-(YPRE(I,3)/CONST*YPRE(I,I
     1MPUR+3))))*100.
   86 CONTINUE
      WRITE(2,2)
      WRITE(2,3)
      IFRAME=FRAME+1.
      WRITE(2,35) MONT,ITIME,IFRAME
      WRITE(4,301)
      WRITE(4,35) MONT,ITIME,IFRAME
      WRITE(2,36) IUNIT
      WRITE(2,36) IFRTR
      IF(RPSI.NE.0.)
     *WRITE(2,9898) RPSI
 9898 FORMAT(*    PRESSURE = *,F10.4,*  PSI*)
      WRITE(2,48) (XTITLE(J,1),J=1,4),(YTITLE(J,8+IMPUR),J=1,3)
   48 FORMAT(T5,4A10,*  VS  *,3A10)
      WRITE(2,95) (XPRE(J),YPRE(J,IMPUR),YPRE(J,3),YPRE(J,3+IMPUR),
     1YPRE(J,6),Y(J),J=1,ILIM)
   95 FORMAT(//T9,*TIME*,T25,*CP*,T40,*V2*,T54,*DCP*,T69,*DV2*,T82,
     1*PERC REJ*//(6(5X,F10.4)))
      PRINT 166,C10,V10
  166 FORMAT(//*  C10 = *,G10.4,*     V10 = *,G10.4//)
      XPRE(ILIM+1)=XMIN(IMPUR+8)
      XPRE(ILIM+2)=DELTAX(IMPUR+8)
      GO TO(96,46),IPLOT
   96 CONTINUE
      WRITE(4,39) XMIN(1),XMAX(1),YMIN(L),YMAX(L),XLEN(1),YLEN(L),
     1DELTAX(1),DELTAY(L)
      READ(1,111) XTIL,YTIL,THAG
      WRITE(2,112) XTIL,YTIL,THAG
      IXWHCH=1
      CALL CALCMP(0.,0.,IDARKP,3)
      CALL BORDER(0.,0.,17.,11.)
      CALL CALCMP(0.,0.,IDARKT,3)
      CALL IDFRAM(14.5,10.1,.14)
      CALL CALCMP(1.5,6.5,IDARKT,3)
      CALL AXIS(0.,0.,XTITLE(1,IXWHCH),-40,XLEN(IXWHCH),0.,XMIN(IXWHCH),
     *DELTAX(IXWHCH))
      CALL HEAD(XTIL,YTIL,THAG)
      CALL SCALE(Y,YLEN(L),ILIM,1)
      WRITE(2,16) Y(ILIM+1),Y(ILIM+2)
   16 FORMAT(1X,*    YSTART = *,F10.4,*    DELTAY = *,F10.4)
      CALL AXIS(0.,0.,YTITLE(1,L),30,YLEN(L),90.,Y(ILIM+1),Y(ILIM+2))
      CALL CALCMP(1.5,6.5,IDARKP,3)
      CALL LINE(XPRE,Y,ILIM,1,1,4)
   46 GO TO(61,47),JSWT
```

```
 47   IMPUR=2
      JSWT=1
      GO TO 45
 99   GO TO (103,102),ISWT
C
C     CLOSE THE PLOT TAPE IF OPENED
C
102   CALL CALCMP(6.,0.,9999,2)
103   STOP
      END
```

```
      SUBROUTINE READIN,RETURNS(IDAV1,IDAV2)
      COMMON/XINP/LENX(5),XINP(505,5)
      COMMON/YINP/LENY(9),YINP(500,9)
      COMMON/TRANSF/IPLOT,IMODL
      COMMON/HEAD/IUNIT(3),IPRTR(3),RPSI
      COMMON/AXES/XMIN(10),XMAX(10),YMIN(10),YMAX(10),XLEN(10),
     1YLEN(10),DELTAX(10),DELTAY(10)
      READ(1,1) IUNIT,IPRTR,IPLOT,IMODL,RPSI
    1 FORMAT(3A10/3A10/2I2/F10.4)
      IF(EOF(1))2,3
    2 RETURN IDAV2
    3 GO TO (4,5),IPLOT
    4 DO 6 I=1,10
      READ(1,7) XMIN(I),XMAX(I),YMIN(I),YMAX(I),XLEN(I),YLEN(I)
    7 FORMAT(6F10.4)
      IF(EOF(1)) 5,22
   22 CONTINUE
      IF(XLEN(I).EQ.0.) XLEN(I)=15.
      IF(YLEN(I).EQ.0.) YLEN(I)=10.
               DELTAX(I)=(XMAX(I)-XMIN(I))/XLEN(I)
      DELTAY(I)=(YMAX(I)-YMIN(I))/YLEN(I)
    6 CONTINUE
    5 CONTINUE
C     READ IN THE X VALUES
      DO 9 I=1,5
      J=1
    9 READ(1,7) XINP(J,I)
      IF(EOF(1)) 8,10
   10  IF(IMODL.EQ.0) GO TO 40
      IF(I.NE.2) GO TO 20
      IF(XINP(1,2).EQ.0.) GO TO 20
               XINP(J,4)=XINP(J,2)/XINP(1,2)
   20 CONTINUE
      IF(I.NE.3) GO TO 30
      IF(XINP(1,3).EQ.0.) GO TO 30
               XINP(J,5)=XINP(J,3)/XINP(1,3)
   30 CONTINUE
      J=J+1
      GO TO 9
    8 LENX(I)=J-1
      IF(IMODL.EQ.0) GO TO 21
      LENX(4)=LENX(2)
      LENX(5)=LENX(3)
   21  CONTINUE
C     READ IN THE Y VALUES
      DO 11 I=1,9
      J=1
   12 READ(1,7) YINP(J,I)
      IF(EOF(1)) 11,13
   13 J=J+1
      GO TO 12
   11 LENY(I)=J-1
      RETURN IDAV1
      END
```

```
      SUBROUTINE HEAD(X,Y,RMAG)
      COMMON/HEAD/IUNIT(3),IPRTR(3),RPSI
      CALL SYMBOL(X,Y-RMAG,RMAG,6HUNIT) ,0.,+6)
      CALL SYMBOL(999.,999.,RMAG,IUNIT,0.,+30)
      CALL SYMBOL(X,(Y-(2.*RMAG+.3)),RMAG,6HPRTR) ,0.,+5)
      CALL SYMBOL(999.,999.,RMAG,IPRTR,0.,30)
      IF(RPSI.EQ.0.) GO TO 1
      CALL SYMBOL(X,(Y-(3.*RMAG+.6)),RMAG,5HPSI) ,0.,5)
      CALL NUMBER(999.,999.,RMAG,RPSI,0.,0)
    1 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE EQNDRA(X,Y,RMAG,B,XLO,XHI,C)
      DIMENSION B(2)
      DIMENSION C(11)
      COMMON/WHICH/IXWHCH,IYWHCH,IXSRT,IYSRT,ICURVE,IORD,N,ISEGNU,ICONT
      CALL SYMBOL(X,Y+.5*RMAG,RMAG,13-IYWHCH-ISEGNU  ,0.,-1)
      CALL SYMBOL(999.,Y,RMAG,6H  Y = ,0.,6)
      GO TO(1,2) ICURVE
    1 CALL NUMBER(999.,999.,RMAG,B(1),0.,3)
      CALL SYMBOL(999.,999.,RMAG,5H EXP(,0.,5)
      CALL NUMBER(999.,999.,RMAG,B(2),0.,3)
      CALL SYMBOL(999.,999.,RMAG,3H X),0.,3)
      GO TO 3
    2 DO 4 I=1,IORD
      INDD = IORD-I+1
      RINDD = INDD
      CALL SYMBOL(999.,999.,RMAG,1H(,0.,1)
      CALL NUMBER(999.,999.,RMAG,C(I),0.,3)
      CALL SYMBOL(999.,999.,RMAG,3H) X,0.,3)
      IF(INDD.EQ.1) GO TO 5
      CALL NUMBER(999.,(Y+(RMAG/2.)),(RMAG/2.),RINDD,0.,-1)
    5 CALL SYMBOL(999.,Y,RMAG,3H + ,0.,3)
    4 CONTINUE
      CALL SYMBOL(999.,999.,RMAG,1H(,0.,1)
      CALL NUMBER(999.,999.,RMAG,C(IORD+1),0.,3)
      CALL SYMBOL(999.,999.,RMAG,1H),0.,1)
    3 CALL SYMBOL(999.,999.,RMAG,5H    (,0.,5)
      CALL NUMBER(999.,999.,RMAG,XLO,0.,0)
      CALL SYMBOL(999.,999.,RMAG,3H<X<,0.,3)
      CALL NUMBER(999.,999.,RMAG,XHI,0.,0)
      CALL SYMBOL(999.,999.,RMAG,1H),0.,1)
      RETURN
      END
```

```
      SUBROUTINE KEY(X,Y,RMAG,IYMHCH)
      COMMON/YTITLE/YTITLE(3,10)
      CALL SYMBOL(X,Y+.5*RMAG,RMAG,IYMHCH-1,0.,-1)
      CALL SYMBOL(999.,Y,RMAG,22H EXPERIMENTAL VALUES) ,0.,22)
      CALL SYMBOL(999.,999.,RMAG,YTITLE(1,IYMHCH),0.,30)
      Y = Y - (RMAG + .14)
      CALL SYMBOL(X,Y,RMAG,31H    PREDICTED VALUE EQUATION(S),0.,31)
      Y = Y - (RMAG + .14)
      RETURN
      END
```

```
      SUBROUTINE BORDER(X0,Y0,X1,Y1)
C     NEW FRAME
      CALL CALCMP(0.,0.,-1000,2)
C     DRAW LINES
      CALL CALCMP(X1,Y0,99,1)
      CALL CALCMP(X1,Y1,99,1)
      CALL CALCMP(X0,Y1,99,1)
      CALL CALCMP(X0,Y0,99,1)
      RETURN
      END
```

```
      SUBROUTINE IOFRAM(X,Y,XMAG)
      COMMON/DATE/MONT,ITIME,FRAME
      DATA FRAME/-1./
      FRAME = FRAME + 1.
      CALL SYMBOL(X,Y,XMAG,6HDATE) ,0.,6)
      CALL SYMBOL(999.,999.,XMAG,MONT,0.,8)
      CALL SYMBOL(X,(Y+.07*XMAG),XMAG,18HNAME) LTC. CICCONE,0.,18)
      CALL SYMBOL(X,(Y+.14*2.*XMAG),XMAG,15HPROGRAM) CICCON,0.,15)
      CALL SYMBOL(X,(Y+.21*3.*XMAG),XMAG,ITIME ,0.,9)
      CALL SYMBOL(999.,999.,XMAG,    5HFRA) ,0.,5)
      CALL NUMBER(999.,999.,XMAG,FRAME,0.,-1)
      RETURN
      END
```

```
      SUBROUTINE POLYFIT(XX,Y,N,M,YC,RES,C,SSR)
      COMMON/XXX/XXX(500,2)
      DIMENSION XX(1,1)
      DIMENSION A(11,12),B(20),X(200)
      EQUIVALENCE(XXX(1,2),X(1))
C   X,Y ARE INPUT ARRAYS
C   N IS THE NUMBER OF POINTS
C   M IS THE ORDER OF THE CURVE TO FIT
C   YC IS THE CALCULATED Y
C   RES IS THE RESIDUAL
C   C IS THE ARRAY OF COEFFICIENTS
C   SSR IS THE STATISTICS RETURN ARRRAY
      DIMENSION        Y(200),YC(200),RES(200),C(11),SSR(5)
      IF (N.LE.1) STOP
      IF (N.LE.500) GO TO 2
      PRINT 1100 , N
 1100 FORMAT(//5X18HNUMBER OF POINTS =,I5,2X19HEXCEEDS MAX. OF 500/
     C 5X18HPROGRAM ERROR STOP)
      STOP 1
    2 IF (M.GT.0) GO TO 3
      PRINT 1200 , M
 1200 FORMAT(//5X5HDEGREE =,I5,9H IN ERROR/5X18HPROGRAM ERROR STOP)
      STOP 2
    3 IF (M.LE.10) GO TO 4
      PRINT 1300 , M
 1300 FORMAT(//5X8HDEGREE =,I5,2X,13HREDUCED TO 10)
      M = 10
    4 CONTINUE
    5 MA = M + 1
      MB = M + 2
      M2 = M + M
      DO 10 I = 1,M2
   10 B(I) = X(1)**I
      DO 20 I = 1,M2
      DO 2  J = 2,N
   20 B(I) = B(I) + X(J)**I
      A(1,MA) = N
      DO 30 I = 2,MA
   30 A(I,MA) = B(I-1)
      DO 40 I = 1,MA
      K = I - 1
      DO 40 J = 2,MA
      L = MA - J + 1
      K = K + 1
   40 A(I,L) = B(K)
      SUM = 0.0
      DO 50 I = 1,N
   50 SUM = SUM - Y(I)
      DO 60 I = 1,M
   60 B(I) = -Y(1)*X(1)**I
      DO 70 I = 1,M
      DO 70 J = 2,N
   70 B(I) = B(I) - Y(J)*X(J)**I
      A(1,MB) = SUM
      DO 80 I = 2,MA
   80 A(I,MB) = B(I-1)
      DO 100 K = 1,M
```

```
      L = K + 1
      DO 90 I = K,MA
      AB = A(I,K)
      DO 90 J = K,MB
   90 A(I,J) = A(I,J)/AB
      DO 100 I = L,MA
      DO 100 J = K,MB
  100 A(I,J) = A(K,J) - A(I,J)
      A(MA,MB) = A(MA,MB)/A(MA,MA)
      DO 110 I = 1,MA
  110 C(I) = -A(I,MB)
      DO 120 J = 2,MA
      K = MA - J + 2
      L = K - 1
      DO 120 I = 1,L
  120 C(I) = C(I) - A(I,K)*C(K)
      SUM = 0.0
      SY = 0.0
      SZ = 0.0
      DO 150 I = 1,N
      P = X(I)
      Q = P*C(1)
      IF(M.EQ.1) GO TO 145
      DO 140 J = 2,M
  140 Q = P*(Q+C(J))
  145 YC(I) = Q + C(MA)
      RES(I) = Y(I) - YC(I)
      SUM = SUM + RES(I)**2
      SY = SY + Y(I)
  150 SZ = SZ + Y(I)**2
      SZ = SZ - SY*SY/FLOAT(N)
      SSR(4) = 1.0 - SUM/SZ
      RETURN
      END
```

```
      SUBROUTINE DERIV(INP)
      COMMON/DERIVA/YPRE(500,5),XPRE(500),LPRE,DVOLCON
      COMMON/EQNS/NCURVE(8),NORDER(8),COEFFS(8,11)
      IF(INP.EQ.4) GO TO 30
      JIND=NCURVE(INP)
      GO TO (1,2),JIND
    1 DO 3 I=1,LPRE
    3 YPRE(I,INP+3)=COEFFS(INP,2)*YPRE(I,INP)
      RETURN
    2 JLIM=NORDER(INP)
      DO 4 I=1,LPRE
      SUM=0.0
      DO 5 J=1,JLIM
    5 SUM=SUM+COEFFS(INP,J)*(JLIM+1-J)*(XPRE(I)**(JLIM-J))
    4 YPRE(I,INP+3)=SUM
      RETURN
   30 DO 6 I=1,LPRE
    6 YPRE(I,6)=DVOLCON
      RETURN
      END
```

```
      SUBROUTINE CALEQN(INP)
      COMMON/EQNS/NCURVE(8),NORDER(8),COEFFS(8,11)
      COMMON/DERIVA/YPRE(500,6),XPRE(500),LPRE,OVOLCON
      JIND=NCURVE(INP)
      GO TO (1,2),JIND
    1 DO 3 I=1,LPRE
    3 YPRE(I,INP)=COEFFS(INP,1)*EXP(XPRE(I)*COEFFS(INP,2))
      RETURN
    2 JLIM=NORDER(INP)+1
      DO 4 I=1,LPRE
      SUM=0.0
      DO 5 J=1,JLIM
    5 SUM=SUM+COEFFS(INP,J)*(XPRE(I)**(JLIM-J))
    4 YPRE(I,INP)=SUM
      RETURN
      END
```

APPENDIX C

COMPUTER ANALYSIS – OBSERVED DATA

```
SANITARY SCIENCE DIVISION REVERSE OSMOSIS
               DATA ANALYSIS
DATE 07/[illegible]/74     TIME 11.32.45.     FRAME NO.    1
ACID WASTEWATER RO STUDY
(CICCONE)
            TIME (HOURS)                    VS      BRINE CONC. - IMPURITY 2
```

X VALUE	Y VALUE	PREDICT Y VALUE	RESIDUAL
.0	3800.0	5676.1	-1876.1
.0	5900.0	5676.1	223.9
.0	5800.0	5676.1	123.9
.0	6400.0	5676.1	723.9
.0	6300.0	5676.1	623.9
2.0	4100.0	5943.7	-1843.7
2.0	6300.0	5943.7	356.3
2.0	6500.0	5943.7	556.3
4.0	5600.0	6316.9	-716.9
4.0	6200.0	6316.9	-116.9
4.0	6600.0	6316.9	283.1
4.0	6900.0	6316.9	583.1
6.0	5800.0	6795.6	-995.6
6.0	8500.0	6795.6	1704.4
8.0	6600.0	7379.9	-779.9
8.0	8500.0	7379.9	1120.1
8.0	7900.0	7379.9	520.1
10.0	9300.0	8369.8	930.2
12.0	9600.0	8865.2	734.8
12.0	9100.0	8865.2	234.8
14.0	8800.0	9766.2	-966.2
16.0	9800.0	10772.8	-972.8
16.0	9000.0	10772.8	-1772.8
16.0	11000.0	10772.8	227.2
18.0	14000.0	11884.9	2115.1
20.0	12000.0	13102.6	-1102.6
20.0	10500.0	13102.6	-2602.6
22.0	17000.0	14425.9	2574.1
26.0	17500.0	17389.0	111.0

```
NUMBER OF OBSERVATIONS IS  29

SQ MULT CORR COEF IS                        .869799E+00

EQUATION IS OF THE FORM Y = C(1)*X**IORD+...+C(IORD+1)
WHERE Y = +      .131954E+02 *X**  2
          +      .137418E+03 *X
          +      .567608E+04

BASIC STATISTICS ABOUT THE Y INPUT ARE
MEAN =  8448.3
SECOND MOMENT =  .10845E+08
THIRD MOMENT =  .44474E+11
FOURTH MOMENT =  .49642E+15
VARIANCE =  .11232E+08
STANDARD DEVIATION =  3351.4
SKEWNESS =  1.2453
KURTOSIS =  1.2211
```

SANITARY SCIENCE DIVISION REVERSE OSMOSIS
DATA ANALYSIS
DATE 17/[illegible]/74   TIME 11.32.45.   FRAME NO. 2
ACID WASTEWATER RO STUDY
(CICCONE)

TIME (HOURS) VS BRINE CONC. - IMPURITY 1

X VALUE	Y VALUE	PREDICT Y VALUE	RESIDUAL
[illegible]	2080.0	2280.9	-200.9
[illegible]	2550.0	2280.9	269.1
[illegible]	2330.0	2280.9	49.1
[illegible]	2500.0	2280.9	219.1
[illegible]	2180.0	2280.9	-100.9
2.0	2080.0	2310.3	-230.3
2.0	2500.0	2310.3	189.7
2.0	2310.0	2310.3	-.3
4.0	2030.0	2323.0	-293.0
4.0	2460.0	2323.0	137.0
4.0	2360.0	2323.0	37.0
4.0	2420.0	2323.0	97.0
6.0	2027.0	2319.1	-292.1
6.0	2190.0	2319.1	-129.1
8.0	2490.0	2298.4	191.6
8.0	2200.0	2298.4	-98.4
8.0	2280.0	2298.4	-18.4
10.0	2160.0	2261.0	-101.0
12.0	2175.0	2207.0	-32.0
12.0	2290.0	2207.0	83.0
14.0	2155.0	2136.2	18.8
16.0	2320.0	2048.7	271.3
16.0	1990.0	2048.7	-58.7
16.0	2190.0	2048.7	141.3
18.0	1825.0	1944.6	-119.6
20.0	2160.0	1823.7	336.3
20.0	1700.0	1823.7	-123.7
22.0	1495.0	1686.1	-191.1
26.0	1310.0	1360.9	-50.9

NUMBER OF OBSERVATIONS IS 29

SQ MULT CORR COEF IS .651898E+00

EQUATION IS OF THE FORM Y = C(1)*X**IORD+...+C(IORD+1)
WHERE Y = + -.203733E+01 *X** 2
+ .188878E+02 *X
+ .228088E+04

BASIC STATISTICS ABOUT THE Y INPUT ARE
MEAN = 2164.0
SECOND MOMENT = 81604.
THIRD MOMENT = -.28944E+08
FOURTH MOMENT = .29940E+11
VARIANCE = 84518.
STANDARD DEVIATION = 290.72
SKEWNESS = -1.2416
KURTOSIS = 1.4967

SANITARY SCIENCE DIVISION REVERSE OSMOSIS
DATA ANALYSIS
DATE 07/09/74 TIME 11.32.45. FRAME NO. 3
ACID WASTEWATER RO STUDY
(CICCONE)

TIME (HOURS) VS PRODUCT CONC. - IMPURITY 1

X VALUE	Y VALUE	PREDICT Y VALUE	RESIDUAL
2.0	2180.0	2489.5	-309.5
2.0	2270.0	2480.5	-210.5
2.0	2590.0	2489.5	100.5
4.0	2170.0	2551.9	-381.9
4.0	2730.0	2551.9	178.1
4.0	2610.0	2551.9	58.1
4.0	2850.0	2551.9	298.1
6.0	2028.0	2604.6	-576.6
6.0	2720.0	2604.6	115.4
8.0	2800.0	2644.8	155.2
8.0	2670.0	2644.8	25.2
8.0	2850.0	2644.8	205.2
10.0	2640.0	2675.4	-35.4
12.0	2650.0	2695.4	-45.4
12.0	2720.0	2695.4	24.6
14.0	2640.0	2704.8	-64.8
16.0	2750.0	2703.7	46.3
16.0	2520.0	2703.7	-183.7
16.0	2840.0	2703.7	136.3
18.0	2790.0	2692.0	98.0
20.0	2860.0	2669.7	190.3
20.0	2210.0	2669.7	-459.7
22.0	2770.0	2636.8	133.2

NUMBER OF OBSERVATIONS IS 23

SQ MULT CORR COEF IS .980186E-01

EQUATION IS OF THE FORM Y = C(1)*X**IORD+...+C(IORD+1)
WHERE Y = + -.132196E+01 *X** 2
+ .393919E+02 *X
+ .241665E+04

BASIC STATISTICS ABOUT THE Y INPUT ARE
MEAN = 2624.7
SECOND MOMENT = 55250.
THIRD MOMENT = -.17457E+08
FOURTH MOMENT = .13925E+11
VARIANCE = 57762.
STANDARD DEVIATION = 240.34
SKEWNESS = -1.3442
KURTOSIS = .57889

SANITARY SCIENCE DIVISION REVERSE OSMOSIS
DATA ANALYSIS
DATE 07/09/74 TIME 11.32.45. FRAME NO. 4
ACID WASTEWATER RO STUDY
(CICCONE)

TIME (HOURS) VS PRODUCT CONC. - IMPURITY 2

X VALUE	Y VALUE	PREDICT Y VALUE	RESIDUAL
2.0	300.0	468.9	-168.9
2.0	700.0	468.9	231.1
2.0	500.0	468.9	31.1
4.0	200.0	483.3	-283.3
4.0	400.0	483.3	-83.3
4.0	460.0	483.3	-23.3
4.0	680.0	483.3	196.7
6.0	480.0	501.6	-21.6
8.0	600.0	523.9	76.1
8.0	470.0	523.9	-53.9
8.0	620.0	523.9	96.1
10.0	510.0	550.1	-40.1
12.0	560.0	580.2	-20.2
12.0	820.0	580.2	239.8
14.0	540.0	614.3	-74.3
16.0	480.0	652.4	-172.4
16.0	500.0	652.4	-152.4
16.0	850.0	652.4	197.6
18.0	800.0	694.3	105.7
20.0	550.0	740.2	-190.2
20.0	690.0	740.2	-50.2
22.0	950.0	790.1	159.9

NUMBER OF OBSERVATIONS IS 22

SQ MULT CORR COEF IS .319387E+00

EQUATION IS OF THE FORM Y = C(1)*X**IORD+...+C(IORD+1)
WHERE Y = + .492494E+00 *X** 2
\+ .224067E+ 1 *X
\+ .455438E+03

BASIC STATISTICS ABOUT THE Y INPUT ARE
MEAN = 575.45
SECOND MOMENT = 30734.
THIRD MOMENT = .862274E+06
FOURTH MOMENT = .253845E+10
VARIANCE = 32197.
STANDARD DEVIATION = 179.44
SKEWNESS = .16012
KURTOSIS = -.15383

SANITARY SCIENCE DIVISION REVERSE OSMOSIS
DATA ANALYSIS
DATE 07/09/74   TIME 11.32.45.   FRAME NO.   5
ACID WASTEWATER RO STUDY
(CICCONE)

TIME (HOURS)   VS VOLUME IN PRODUCT TANK (GALS.)

X VALUE	Y VALUE	PREDICT Y VALUE	RESIDUAL
0.0	0.0	3.5	-3.5
0.0	0.0	3.5	-3.5
0.0	0.0	3.5	-3.5
.0	0.0	3.5	-3.5
2.0	22.5	29.2	-6.7
2.0	23.8	29.2	-5.4
2.0	61.0	29.2	31.8
4.0	45.0	53.9	-8.9
4.0	45.0	53.9	-8.9
4.0	88.0	53.9	34.1
4.0	35.0	53.9	-18.9
6.0	57.5	77.6	-20.1
6.0	104.0	77.6	26.4
8.0	70.0	100.1	-30.1
8.0	119.0	100.1	18.9
8.0	85.0	100.1	-15.1
10.0	144.0	121.6	22.4
12.0	163.0	142.0	21.0
12.0	121.0	142.0	-21.0
14.0	182.0	161.4	20.6
16.0	145.0	179.6	-34.6
16.0	198.0	179.6	18.4
16.0	160.0	179.6	-19.6
18.0	200.0	196.8	3.2
20.0	185.5	212.9	-27.4
20.0	240.0	212.9	27.1
22.0	235.0	227.9	7.1

NUMBER OF OBSERVATIONS IS 27

SQ MULT CORR COEF IS   .929020E+00

EQUATION IS OF THE FORM Y = C(1)*X**IORD+...+C(IORD+1)
WHERE Y = +   -.134436E+00 *X** 2
    +   .131615E+02 *X
    +   .345023E+01

BASIC STATISTICS ABOUT THE Y INPUT ARE
MEAN = 1[illegible]1.03
SECOND MOMENT = 5572.7
THIRD MOMENT = .1[illegible]397E+06
FOURTH MOMENT = .57157E+08
VARIANCE = 5787.1
STANDARD DEVIATION = 76.073
SKEWNESS = .24992
KURTOSIS = -1.1595